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# Both facilitatory and inhibitory impairments underlie age-related differences of proactive cognitive control across the adult lifespan

Pascal W.M. Van Gerven[a,*], Petra P.M. Hurks[b], Jos J. Adam[c]

[a] School of Health Professions Education (SHE), Department of Educational Development & Research, Faculty of Health, Medicine and Life Sciences, Maastricht University, Maastricht, The Netherlands

[b] Department of Neuropsychology and Psychopharmacology, Faculty of Psychology and Neuroscience, Maastricht University, Maastricht, The Netherlands

[c] Department of Human Biology and Movement Sciences, Faculty of Health, Medicine and Life Sciences, Maastricht University, Maastricht, The Netherlands

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ABSTRACT

We investigated two components of proactive cognitive control, response facilitation and response inhibition, in an adult lifespan sample ($N$ = 544, age range = 18–91 years) by administering two response-preparation tasks: a procue task, primarily involving facilitation, and an anticue task, involving both facilitation and inhibition. Cues in both tasks corresponded with the index and middle fingers of either the left or right hand. After a random preparation interval (PI) of 100–850 ms following the onset of the cue signal, a single-target stimulus indicated the required response. Where procues were spatially aligned with the two fingers of the responding hand, anticues consistently indicated the two fingers of the opposite hand, requiring a remapping of cue location and response hand. This remapping requires inhibition to suppress the automatic activation of the ipsilateral responses. Previous research revealed typical reaction time (RT) profiles for procues and anticues as a function of PI. Whereas procues generate RT benefits (relative to a neutral-cue condition) already at short PIs, which increase with longer PIs, anticues generate RT costs at short PIs and RT benefits at longer PIs. Our results showed that, in the anticue task, older participants needed more preparation time to turn RT costs into RT benefits than younger participants, revealing an age-related deficit of response inhibition. Moreover, in both tasks, older participants were less able to increase RT benefits with longer PIs, revealing a deficit of response facilitation. We conclude that both facilitatory and inhibitory impairments contribute to age-related deficiencies in proactive cognitive control.

## 1. Introduction

Proactive cognitive control helps people to optimize their performance by anticipating upcoming events that require a context-specific response (Braver, 2012; Braver, Gray, & Burgess, 2007). To exert effective proactive control, the presence of reliable predictive cues is essential. Typical cognitive tasks that provide such predictive cues are the continuous performance task (AX-CPT; Locke & Braver, 2008) and the anticue task (Adam, Jennings, Bovend'Eerdt, Hurks, & Van Gerven, 2015). Using the anticue task, we have recently revealed an inverted U-shaped relation between age and performance, entailing a strong increase of the ability to exert proactive control during childhood, adolescence, and early adulthood, a period of relative stability in middle and late adulthood (26–60 years), and a gradual decrease of proactive control after the age of 60 (Van Gerven, Hurks, Bovend'Eerdt, & Adam, 2016). Moreover, we have shown that the rise and fall of proactive cognitive control is accompanied by a respective decrease and increase of a primarily reactive, stimulus-driven, mode of cognitive control. This developmental pattern resonates with findings from neuroimaging research, which suggest a relatively late maturation combined with a relatively early degeneration of brain structures associated with cognitive control in the frontal, temporal, and parietal cortices (e.g., Douaud et al., 2014; Sowell et al., 2003; Tamnes et al., 2013). In the current adult lifespan study, we aimed to study two mechanisms of proactive cognitive control: facilitation and inhibition. We did this by comparing performance on the procue task, which primarily requires response facilitation, with performance on the anticue task, which requires both response facilitation and response inhibition.

The *procue* task originates from the finger precuing task, which was devised by Miller (1982) and further developed by Adam and colleagues (e.g., Adam et al., 1998). In the procue task, cue and response locations are spatially aligned, or *congruent*. The *anticue* task, on the

* Corresponding author at: School of Health Professions Education (SHE), Department of Educational Development & Research, Faculty of Health, Medicine and Life Sciences, Maastricht University, P.O. Box 616, 6200 MD Maastricht, The Netherlands.

*E-mail address:* p.vangerven@maastrichtuniversity.nl (P.W.M. Van Gerven).

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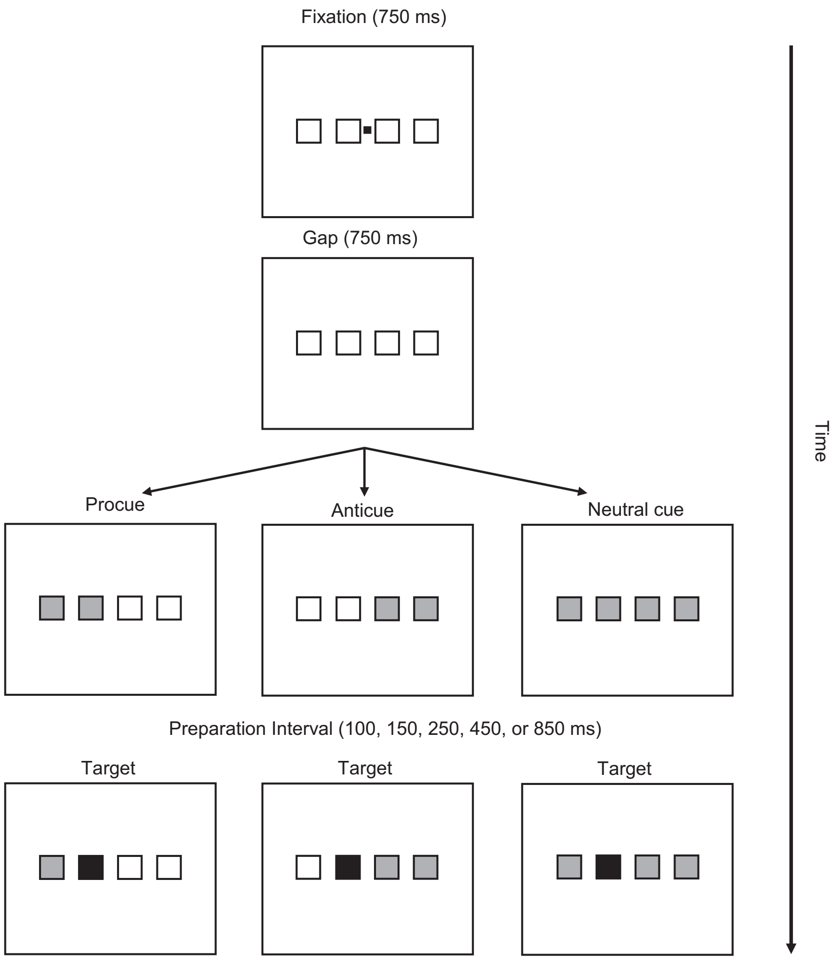


**Fig. 1.** Flowchart of the tasks with procues, anticues, and neutral cues, respectively. The participant sees four empty boxes in a horizontal row. After some time, two boxes turn red (gray in the figure). This is the cue, indicating the index and middle fingers of either the left or right hand. A *procue* indicates the fingers that need to be prepared for a probable response in a spatially compatible manner, that is: A left-sided cue indicates a left-hand response and a right-sided cue indicates a right-hand response. An *anticue*, however, indicates the fingers of the opposite hand: A left-sided cue requires a right-hand response and vice versa. Thus, anticues require preparation of the fingers opposite to the side of the cue. A *neutral* cue, finally, indicates all possible response locations and serves as a control condition against which the effects of procues and anticues can be evaluated. After a random preparation interval (PI) of 100, 150, 250, 450, or 850 ms, one of the two cued squares turns green (black in the figure). This is the imperative target stimulus, indicating which finger needs to give a response.

other hand, was recently developed by Adam et al. (2015) to study the temporal dynamics of proactive control. This task is aimed at the resolution of response conflict in the manual motor system because the cue and response locations in this task are *incongruent*. Fig. 1 shows the subsequent phases of a trial in the procue and anticue tasks in comparison to a control condition with *neutral* cues, which indicate all possible response locations and, therefore, do not provide any potential RT benefits relative to procues and anticues.

Where procues trigger natural, partly automatic, response preparation processes, anticues require a consistent remapping of cue location and response hand. Previous research has shown that, given enough preparation time, both procues and anticues lead to faster responses relative to neutral cues because their predictive value regarding upcoming events enables the participant to exert proactive cognitive control by preparing a subset of possible responses (i.e., by transforming the default 4-choice RT task into a less complex 2-choice RT task; Adam et al., 2015). Procues typically take less preparation time – that is, the time between the cue and the stimulus, or *preparation interval* (PI) – to yield a reaction time (RT) benefit than anticues. That is, procues already lead to RT benefits at short PIs due to spatial congruency, which prompts fast, automatic response activation. These early benefits can be augmented by intentional preparation at longer PIs. Anticues, however, initially lead to RT costs if PIs are too short. This is because anticues automatically prime the fingers of the wrong hand. Overcoming this automatic priming requires response inhibition, which inflates RT. At longer PIs, participants are not only able to exert response inhibition of the fingers ipsilateral to the anticue, but also to intentionally prepare the fingers contralateral to the anticue. This makes it possible to transform the initial RT cost into a RT benefit. The necessity of inhibition in the anticue task to overcome automatically induced but erroneous responses was convincingly demonstrated by Adam et al. (2015). They did not only administer a response selection, or choice, task with anticues, but also a simple detection task. In the detection version of the anticue task, cues and stimuli were exactly the same as in the regular, choice, version of the task, but participants were required to respond to any of the four possible stimuli with the same finger, pressing one response key. Using this procedure, the involvement of response selection processes was minimized. Where the typical cross-over pattern of RTs was seen in the choice version of the anticue task (RT costs at shorter PIs turning into RT benefits at longer PIs), this pattern was not seen in the detection version of the task. This suggests that only the choice version of the anticue task involves the need to resolve conflict induced by the incongruence between anticues and effectors (fingers) by inhibition of automatic response tendencies.

A relevant theoretical framework specifying the processes required for optimal performance on cued tasks is the dual-route model by Kornblum, Hasbroucq, and Osman (1990). This model postulates that motor responses are driven by both facilitatory and inhibitory mechanisms (see Ridderinkhof, 2002, for a discussion and refinement of this model). That is, responses to a stimulus can follow either a direct, facilitatory, or an indirect, inhibitory, route. The direct route is independent of instructions specifying stimulus-response mappings, which means that cues automatically activate spatially congruent effectors, even if the instructions say that spatially incongruent effectors need to be activated, such as in the anticue task. The indirect route, on the other hand, involves selective suppression of effectors that are not supposed to give a response. This route is taken if there is a conflict between stimulus and response locations. In the anticue task, response conflict may arise from the automatic activation of the fingers ipsilateral to the cue while a response is required from one of the fingers